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Chapter Thirteen
INTERSECTIONS AT-GRADE

13.1 GENERAL

13.1.1 Chapter Contents

The intersection is an important part of the highway system. The operational efficiency, capacity, safety and cost of the system depend largely upon its design, especially in urban areas. The primary objective of intersection design is to reduce potential conflicts between vehicles, bicycles and pedestrians while providing for the convenience, ease and comfort of those traversing the intersection. In general, the Geometrics Unit within the Traffic Engineering Section performs all work on the geometric design of major intersections including those with large trucks, pedestrians, turn lanes, turning roadways, etc. The Geometrics Unit will prepare all the necessary detail sheets to clearly identify all geometric features. The road designer will place these sheets into the final plans and will calculate the necessary roadway quantities for intersections and auxiliary lanes. Any revisions to these detail sheets will be conducted by the Geometrics Unit.

Chapter Thirteen discusses the geometric design of simple at-grade intersections typically conducted by the road designer including intersection alignment and profile, turn lane guidelines, intersection sight distance and approaches. Chapter Twenty-eight and other chapters of the *Traffic Engineering Manual* presents considerably more information on intersections at-grade which may apply to a project administrated by the Road Design Section. These include:

1. design vehicles for intersections (Section 28.2.2);
2. intersection spacing (Section 28.2.3);
3. capacity and level of service (Chapter Thirty);
4. turning radii types and design (Section 28.3);
5. auxiliary turn lane designs including widths, turn lane lengths, offset turn lanes and dual turn lanes (Section 28.4);
6. turning roadways (Section 28.5);
7. intersection acceleration lanes (Section 28.6);

8. channelization (Section 28.7); and

9. median openings (Section 28.8).

13.1.2 Definitions

1. Approach. A road providing access from a public way to a highway, street, road, or to an abutting property.

2. Begin Curb Return (BCR). The point along the mainline pavement edge where the curb return of an intersection meets the tangent portion.

3. Channelization. The directing of traffic through an intersection by the use of pavement markings (including striping, raised reflectors, etc.), medial separators or raised islands.

4. Comfort Criteria. Criteria which is based on the comfort effect of change in vertical direction in a sag vertical curve because of the combined gravitational and centrifugal forces.

5. Corner Island. A raised or painted island to channel the right-turn movement.

6. Design Vehicle. The vehicle used to determine turning radii, off-tracking characteristics, pavement designs, etc., at intersections.

7. End Curb Return (ECR). The point along the minor roadway pavement edge where the curb return of an intersection meets the tangent portion.

8. Grade Separation. A crossing of two highways, or a highway and a railroad, at different levels.

9. Interchange. A system of ramps in conjunction with one or more grade separations, providing for the movement of traffic between two or more roadways on different levels.

10. Intersection. The general area where two or more highways join or cross at grade.

11. Intersection Sight Distance (ISD). The sight distance required within the corners of intersections to safely allow a variety of vehicular access or crossing maneuvers based on the type of traffic control at the intersection.

12. Islands. Channelization (raised or flush) in which traffic passing on both sides is traveling in the same direction.

13. Landing Area. The area approaching an intersection for stopping and storage of vehicles.

14. Medial Separator. Channelization which separates opposing traffic flows, alerts the driver to the cross road ahead and regulates traffic through the intersection.

15. Median Opening. Openings in the median (raised or depressed) on divided facilities which allow vehicles to cross the facility or to make a U-turn.

16. No Control Intersection. An intersection where none of the legs are controlled by a traffic control device.

17. Parking Lane. An additional lane for the parking of vehicles.

18. Return. The circular segment of curb at an intersection which connects the tangent portions of the intersecting legs.

19. Signalized Intersection. An intersection where all legs are controlled by a traffic signal.

20. Stop Controlled Intersection. An intersection where one or more legs are controlled by a stop sign.

21. Turn Lane. An auxiliary lane adjoining the through traveled way for speed change, storage and turning.

22. Turning Roadway. A channelized roadway (created by an island) connecting two legs of an at-grade intersection. Interchange ramps are not considered turning roadways.

23. Turning Template. A graphic representation of a design vehicle's turning path depicting various angles of turns for use in determining acceptable turning radii designs.

24. Yield Controlled Intersection. An intersection where one or more legs are controlled by a yield sign.

13.2 GENERAL DESIGN CONTROLS

13.2.1 Intersection Alignment

13.2.1.1 Horizontal Curves

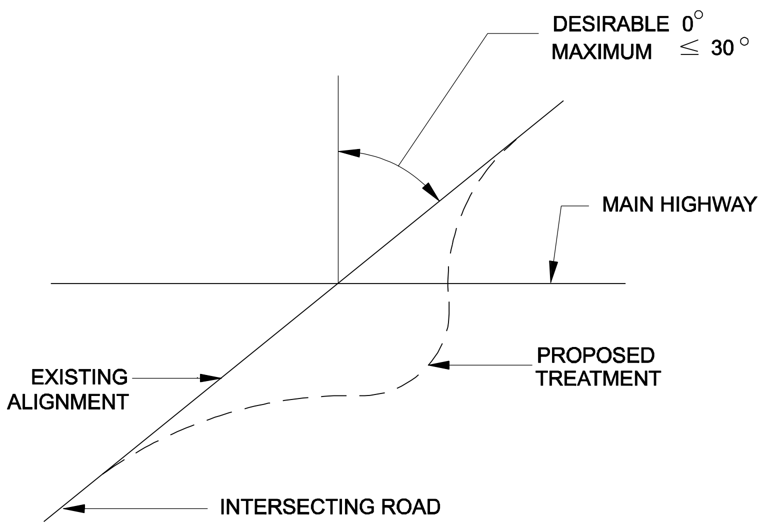
Preferably, an intersection between two roadways should be on tangent sections. When a minor road intersects a major road on a horizontal curve, the geometric design of the intersection becomes significantly more complicated, particularly for sight distance, turning movements, channelization and superelevation.

13.2.1.2 Angle of Intersection

Desirably, roadways should intersect at or as close to 90º as practical. Skewed intersections are undesirable for several reasons:

1. Vehicular turning movements become more restricted.
2. The accommodation of large trucks for turning may require additional pavement and channelization.
3. The exposure time for vehicles and pedestrians crossing the main traffic flow is increased.
4. The driver's line of sight for one of the sight triangles becomes restricted.

The intersection angle should not exceed 30º from perpendicular. Intersections with a skew greater than 30º from perpendicular must be reviewed and documented. For existing intersections, it will rarely be warranted to realign the intersection if its skew is within 30º of perpendicular. Where skew angles greater than 30º are present, the intersection may require geometric improvements (realignment, auxiliary lanes, greater corner sight distance). Figure 13.2A illustrates various angles of intersection and potential improvements that can be made to the alignment.



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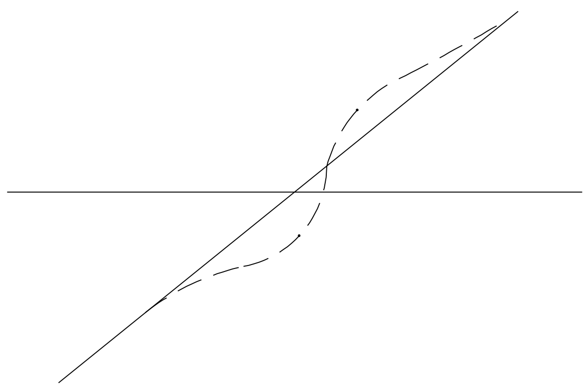

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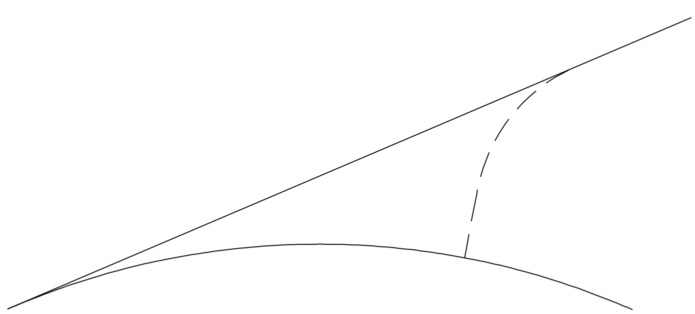


-C-

Note: Check the superelevation on the horizontal curve.

TREATMENTS FOR SKEWED INTERSECTIONS
Figure 13.2A

13.2.2 Intersection Profile

13.2.2.1 Gradient

The "landing area" is that portion of intersecting highways, local roads, and public and private approaches that will be used for the storage of stopped vehicles. Desirably, the landing area will slope downward from the intersection on a gradient not to exceed 3%. The landing area may slope upward from the intersection on a gradient not to exceed 3% if site constraints warrant. However, an upward sloping landing area should be avoided if practical. At a minimum, the landing area should be 25 m for public roads and 7.5 m for other facilities.

The gradient of the approach beyond the 7.5 m landing should not exceed 6% for private approaches unless site constraints preclude its use. Use of steeper approach slopes must be documented in the Alignment Review Report.

13.2.2.2 Cross Slope Transitions

One or both of the roadways approaching the intersection may need to be transitioned (or warped) to match or coordinate the cross slope and grade at the intersection. The designer should consider the following:

1. Stop Controlled. When the minor road is stop controlled, the profile gradeline and cross slope of the major road will normally be maintained through an intersection, and the cross slope of the stop-controlled leg will be transitioned to match the major road grade.

2. Signalized Intersection. At signalized intersections, or potential signalized intersections, the cross slope of the minor road will typically be transitioned to meet the grade of the major road. If both intersecting roads have approximately equal importance, the designer may want to consider transitioning both roadways to form a plane section through the intersection. Where compromises are necessary between the two major roadways, the smoother riding characteristics should be provided for the roadway with the higher travel speeds.

3. Transition Distance. In rural areas, transitioning from the normal crown to a warped section should be accomplished in a distance of 15 m. The 15 m transition length is also desirable for urban areas but, at a minimum, the transition may be accomplished within the curb return; see Figure 13.2B.

13.2.2.3 Vertical Profile

Where the profile of the minor road is adjusted to meet the major road, this will result in angular breaks for traffic on the minor road if no vertical curve is inserted. The following options are presented in order from the most desirable to the least desirable; see Figure 13.2C:

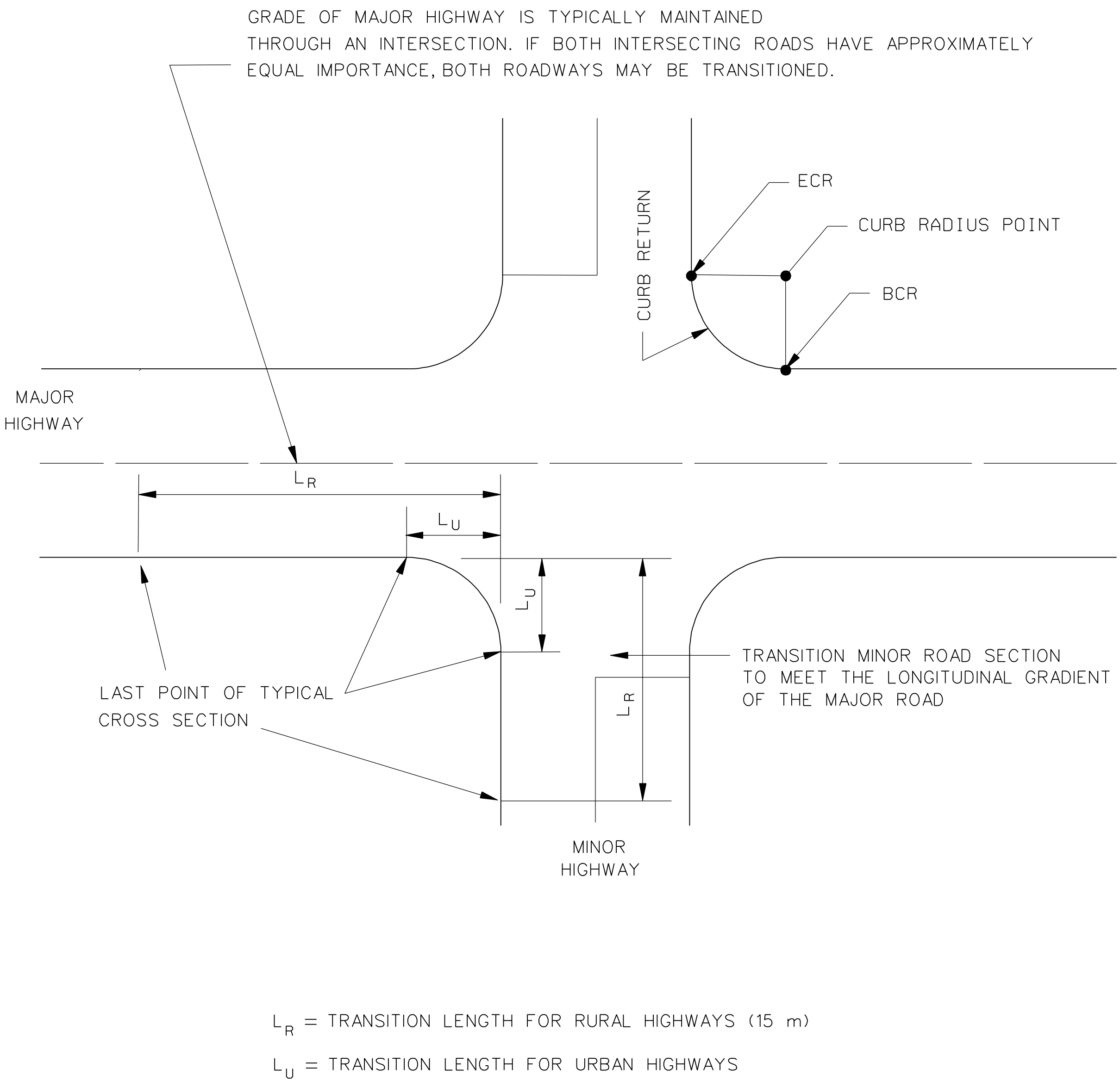
1. Vertical Curves (SSD). Desirably, vertical curves will be used through an intersection which meet the criteria for stopping sight distance as described in Chapter Ten. For stop-controlled legs, design the approach landing vertical curve with a 50 km/h design speed; at free-flowing legs and at all legs of a signalized or proposed future signalized intersection, use the design speed of the roadway to design the vertical curve. The grades of the tangents for the vertical curve are the grade of the landing area (G_1) and the profile grade of the minor roadway (G_2); see Figure 13.2C. The Point of Vertical Tangency (PVT) will be located at the end of the landing (25 m from the paved shoulder of the mainline). The PVT can be shifted onto the landing area if the gradient of the landing does not exceed 3%.

2. Sag Vertical Curves (Comfort). For sag vertical curves, the next most desirable option is to design the sag to meet the comfort criteria. The length of vertical curve can be determined as follows:

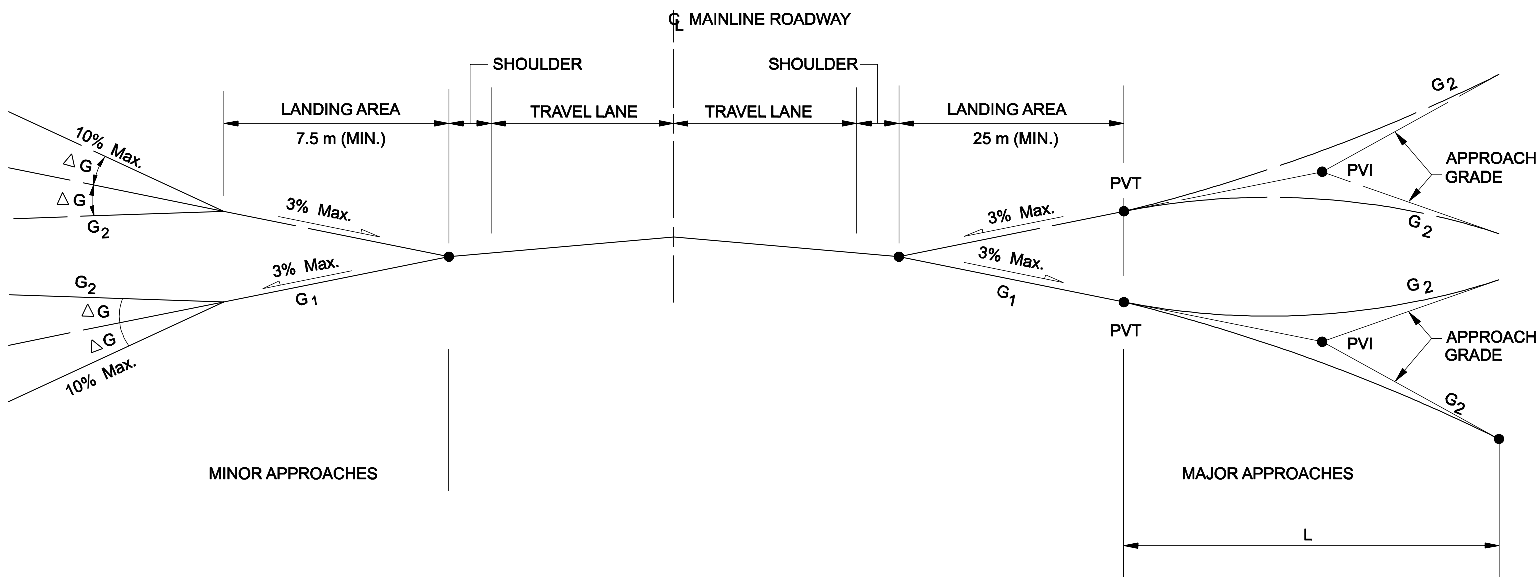
$$L = \frac{AV^2}{395}$$

Where:

L	=	length of vertical curve, m
A	=	algebraic difference between grades, %
V	=	design speed, km/h



PAVEMENT TRANSITIONS THROUGH INTERSECTIONS
Figure 13.2B



Notes:

1. At signalized intersections, the most desirable rotation option will be to transition the cross slopes of all approach legs into a plane section through the intersection.

2. If practical, the gradient of the landing area where vehicles may be stored should not exceed 3%.

3. See Figure 13.2D for maximum allowable ΔG's.

4. Actual field conditions will determine the final design.

VERTICAL PROFILES OF INTERSECTING ROADS
Figure 13.2C

$K=(0.034V)^2$ (Sag Curves)

$K=(0.024V)^2$ (Crest Curves)

$L=KA$

Where:

K = the horizontal distance in meters needed to produce a 1% change in the gradient along the curve

A = algebraic difference between the two tangent grades, %

V = design speed, km/h

L = length of vertical curve, m

4. Angular Breaks. Angular breaks between the landing area and the approach gradient are typically used on minor approaches; see Figure 13.2C. For major approaches, it may be impractical to provide vertical curves on the approaches under some restricted conditions; i.e., angular breaks are necessary through the intersection. Figure 13.2D provides the maximum allowable angular breaks for various design speeds. Where angular breaks are used, the minimum distance between successive angle points should be at least 5 m.

13.2.2.4 Intersection Sight Distance

The designer needs to consider the effect the intersection profile and alignment will have on intersection sight distance. Landings with steep upgrades, may put the driver's eye below or in line with roadway appurtances (e.g., guardrail, signs). Also, large skewed intersections will require the driver to look back over their shoulder. For more information on intersection sight distance, see Section 13.4.

13.2.3 Turning Radii

The road designer is responsible for the turning radii design on minor intersections. Typically these designs will consist of simple curve radius. The designer should check the intersection with design vehicle turning template to ensure the design is adequate.

For intersections where trucks, pedestrians, turn lanes, turning roadways, etc., are a concern, contact the Geometrics Unit in the Traffic Engineering Section for additional guidance.

Design Speed (km/h)	Crest Vertical Curves (ΔG)	Sag Vertical Curves (ΔG)
30	7.5%	4.8%
40	5.4%	2.7%
50	3.5%	1.7%
60	2.4%	1.2%
70	1.8%	0.9%
80	1.4%	0.7%
90	1.1%	0.5%
100	0.9%	0.4%

Notes:

1. *Design speed applies to the roadway with the angular break. Typically, this will be the minor roadway.*

2. *The angular break (ΔG) occurs between the landing area and approach roadway; see Figure 13.2C.*

MAXIMUM CHANGE IN GRADES WITHOUT A VERTICAL CURVE

Figure 13.2D

13.3 AUXILIARY TURN LANES

13.3.1 Turn Lane Guidelines

13.3.1.1 Guidelines for Right-Turn Lanes

Exclusive right-turn lanes should be considered:

1. at the free-flowing leg of any unsignalized intersection on a 2-lane urban or rural highway which satisfies the criteria in Figure 13.3A;

2. at the free-flowing leg of any unsignalized intersection on a high-speed, 4-lane urban or rural highway which satisfies the criteria in Figure 13.3B;

3. at any intersection where a capacity analysis determines a right-turn lane is necessary to meet the level-of-service criteria;

4. as a general rule, at any signalized intersection where the projected right-turning volume is greater than 300 vph and where there is greater than 300 vph per lane on the mainline; or

5. at any intersection where the crash trend involves right-turning vehicles.

13.3.1.2 Guidelines for Left-Turn Lanes

Exclusive left-turn lanes should be considered:

1. at all public intersections on all multilane urban and rural highways, regardless of traffic volumes;

2. at the free-flowing leg of any unsignalized intersection on a 2-lane urban or rural highway which satisfies the criteria in Figures 13.3C, 13.3D, 13.3E or 13.3F;

3. at any intersection where a capacity analysis determines a left-turn lane is necessary to meet the level-of-service criteria;

4. as a general rule on the major roadway, at any signalized intersection;

5. at high-volume driveway approaches which satisfy the criteria in Figures 13.3C, 13.3D, 13.3E or 13.3F; or

6. at any intersection where the accident experience, traffic operations, sight distance restrictions (e.g., intersection beyond a crest vertical curve), or engineering judgment indicates a significant conflict related to left-turning vehicles.

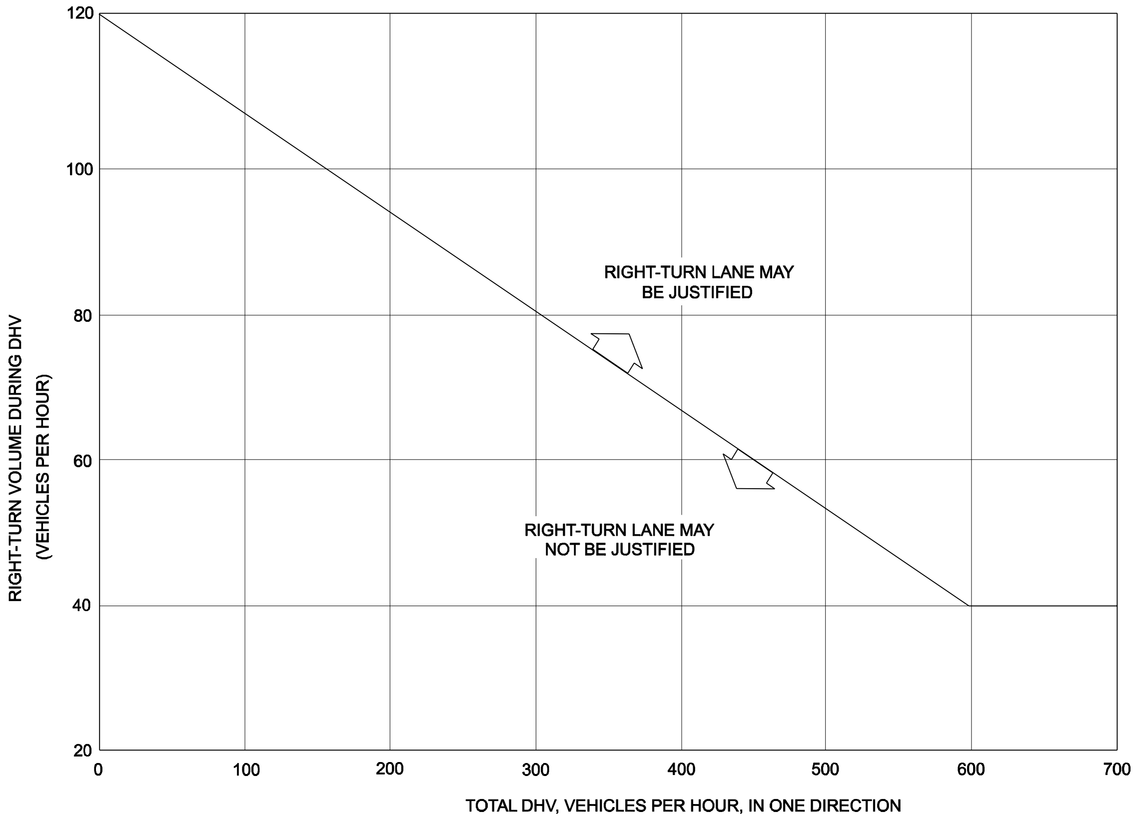
13.3.1.3 Sight Distance

When considering a right-turn lane on a through roadway, give specific attention to visibility on the side street. Decelerating vehicles in the auxiliary lane can create a moving sight obstruction. Proper placement of the stop bar on the side streets and lateral placement of right-turn lanes will allow a vehicle on the side approach to see the approaching through traffic. Combination of medial separators and channelizing islands can be used to control proper placement of stopped and decelerating vehicles.

When establishing a left-turn lane, the designer needs to consider access to and from private properties on the legs to the intersection.

13.3.2 Design of Turn Lanes

For the design of turn lanes (e.g., widths, lengths, types), see Section 28.4 of the *Traffic Engineering Manual*.



Note: For highways with a design speed below 80 km/h with a DHV <300 and where right turns > 40, an adjustment should be used. To read the vertical axis of the chart, subtract 20 from the actual number of right turns.

Example

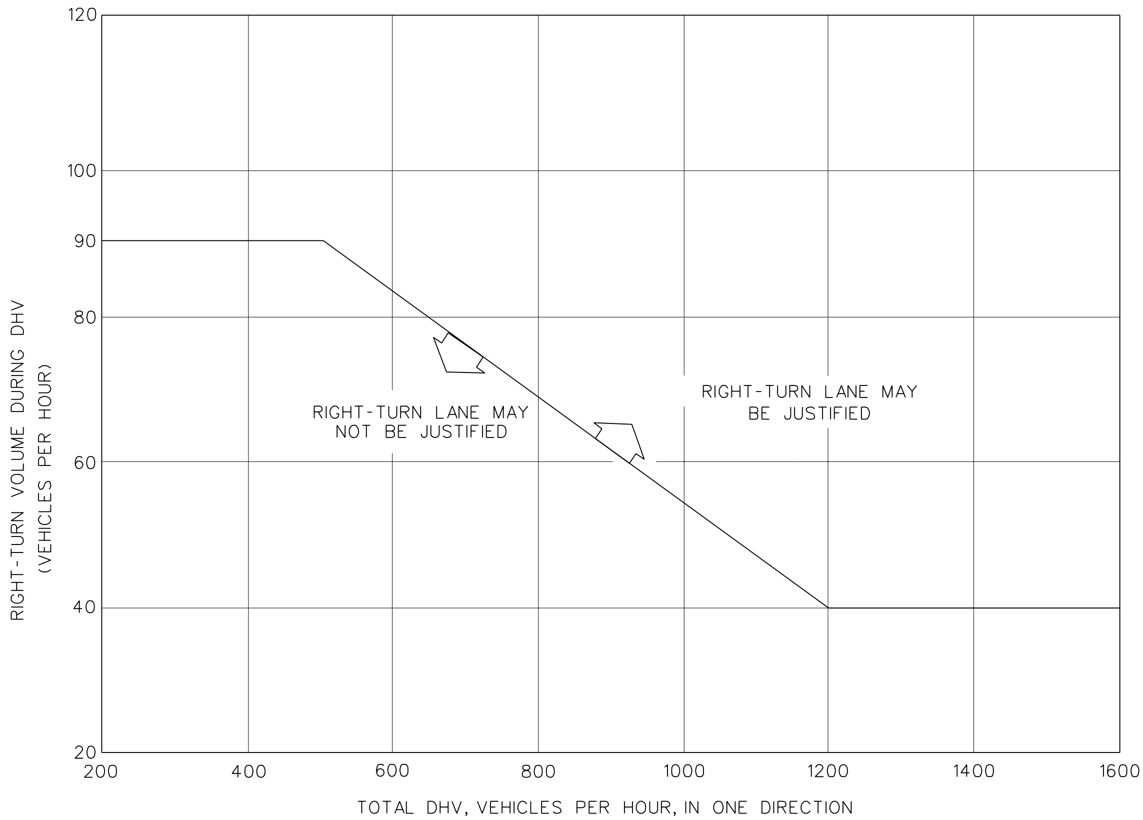
Given:	Design Speed	=	60 km/h
	DHV	=	250 vph
	Right Turns	=	100 vph

Problem: Determine if a right-turn lane is necessary.

Solution: To read the vertical axis, use 100 - 20 = 80 vph. The figure indicates that a right-turn lane is not necessary, unless other factors (e.g., high accident rate) indicate a lane is needed.

GUIDELINES FOR RIGHT-TURN LANES AT UNSIGNALIZED INTERSECTIONS ON 2-LANE HIGHWAYS

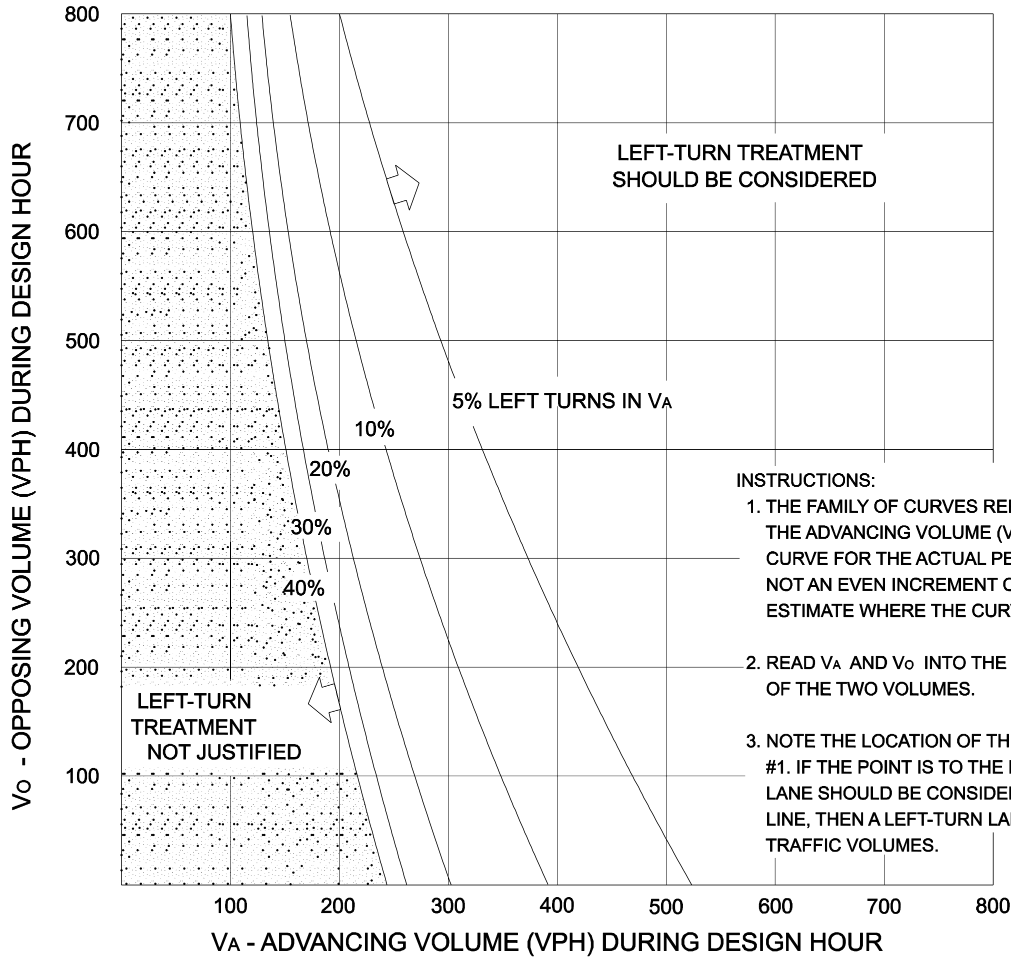
Figure 13.3A



Note: Figure is only applicable on highways with a design speed of 80 km/h or greater.

GUIDELINES FOR RIGHT-TURN LANES AT UNSIGNALIZED INTERSECTIONS ON 4-LANE HIGHWAYS

Figure 13.3B

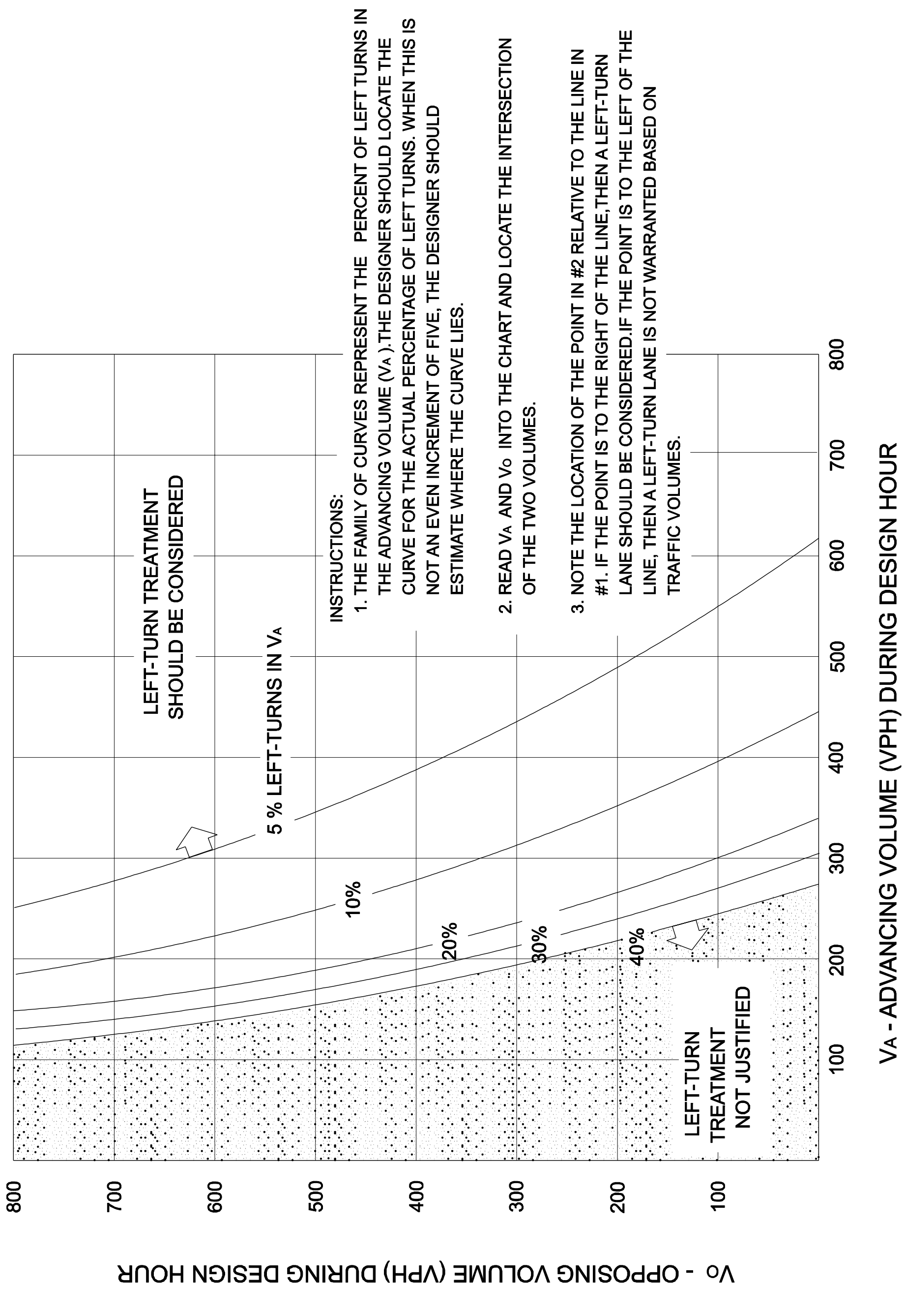


INSTRUCTIONS:

1. THE FAMILY OF CURVES REPRESENT THE PERCENT OF LEFT TURNS IN THE ADVANCING VOLUME (V_A).THE DESIGNER SHOULD LOCATE THE CURVE FOR THE ACTUAL PERCENTAGE OF LEFT TURNS. WHEN THIS IS NOT AN EVEN INCREMENT OF FIVE, THE DESIGNER SHOULD ESTIMATE WHERE THE CURVE LIES.
2. READ V_A AND V_O INTO THE CHART AND LOCATE THE INTERSECTION OF THE TWO VOLUMES.
3. NOTE THE LOCATION OF THE POINT IN #2 RELATIVE TO THE LINE IN #1. IF THE POINT IS TO THE RIGHT OF THE LINE,THEN A LEFT-TURN LANE SHOULD BE CONSIDERED.IF THE POINT IS TO THE LEFT OF THE LINE, THEN A LEFT-TURN LANE IS NOT WARRANTED BASED ON TRAFFIC VOLUMES.

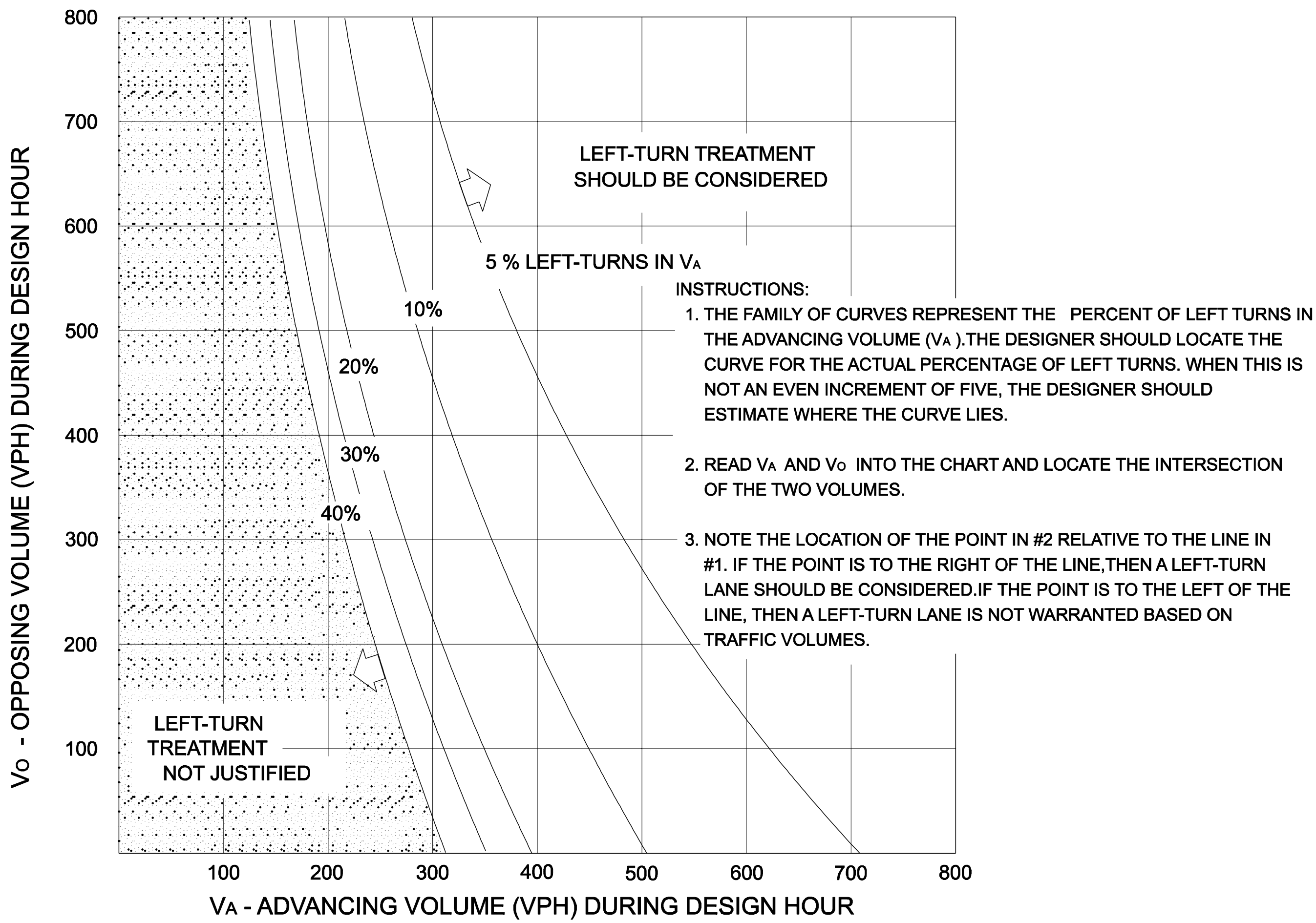
VOLUME GUIDELINES FOR LEFT-TURN LANES AT UNSIGNALIZED INTERSECTIONS ON 2-LANE HIGHWAYS (100 KM/H)

Figure 13.3C



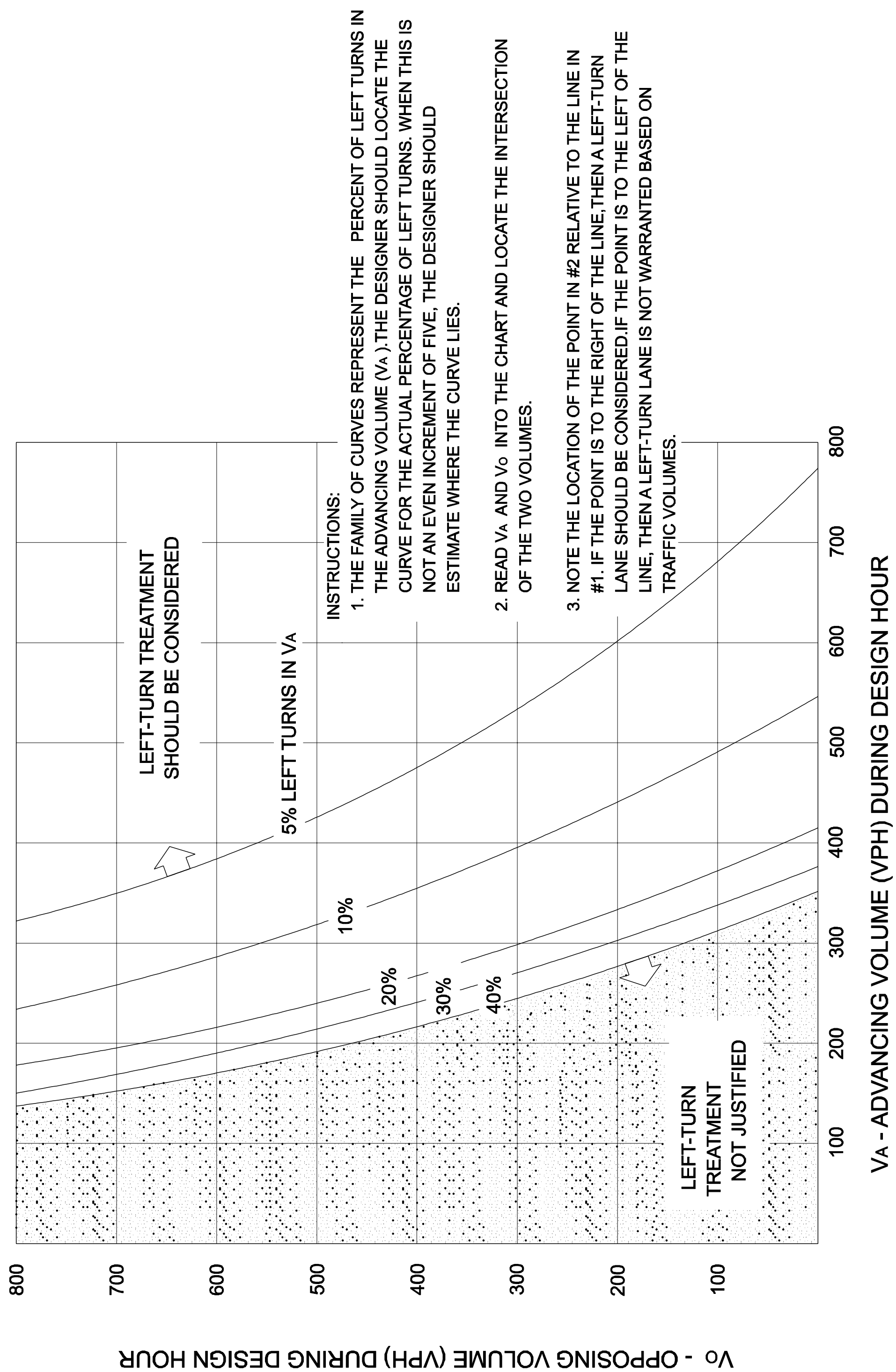
VOLUME GUIDELINES FOR LEFT-TURN LANES AT UNSIGNALIZED INTERSECTIONS ON 2-LANE HIGHWAYS (90 KM/H)

Figure 13.3D



VOLUME GUIDELINES FOR LEFT-TURN LANES AT UNSIGNALIZED INTERSECTIONS ON 2-LANE HIGHWAYS (80 KM/H)

Figure 13.3E



VOLUME GUIDELINES FOR LEFT-TURN LANES AT UNSIGNALIZED INTERSECTIONS ON 2-LANE HIGHWAYS (70 KM/H)

Figure 13.3F

13.4 INTERSECTION SIGHT DISTANCE

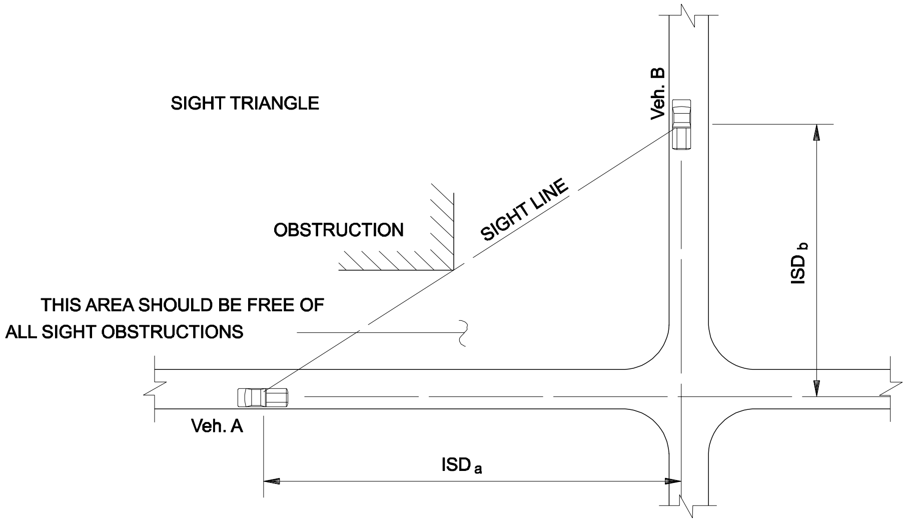
For an at-grade intersection to operate properly, adequate sight distance should be available. The designer should provide sufficient sight distance for a driver to perceive potential conflicts and to perform the actions needed to negotiate the intersection safely. The additional costs and impacts of removing sight obstructions are often justified. If it is impractical to remove an obstruction blocking the sight distance, the designer should consider providing traffic control devices or design applications (e.g., warning signs, turn lanes) which may not otherwise be considered.

In general, ISD refers to the corner sight distance available in intersection quadrants which allows a driver approaching an intersection to observe the actions of vehicles on the crossing leg(s). ISD evaluations involve establishing the needed sight triangle in each quadrant by determining the legs of the triangle on the two crossing roadways. The necessary clear sight triangle is based on the type of traffic control at the intersection and on the design speeds of the two roadways.

The Department uses gap accept as its basic concept in the design of intersection sight distance. This gap acceptance design is based on the criteria and theory presented in NCHRP Report 383, *Intersection Sight Distance*.

13.4.1 <u>No Traffic Control</u>

Intersections between low-volume and low-speed roads/streets may have no traffic control. At these intersections, sufficient corner sight distance should be available to allow approaching vehicles to adjust their speed to avoid a collision, typically 50 percent of their mid-block running speed. Figure 13.4A provides the ISD criteria for intersections with no traffic control. For approach grades greater than 3%, adjust the ISD values obtained in Figure 13.4A with the applicable ratios in Figure 13.4B.



Design Speed (km/h)	20	30	40	50	60
*Intersection Sight Distance (m)	20	25	30	40	50

Note: For approach grades greater than 3%, multiply the sight distance values in this table by the appropriate adjustment factor from Figure 13.4B. The grade adjustment is based on the approach roadway grade only.

Example

Given: No traffic control at intersection

Design speed --- 60 km/h (Highway A)

40 km/h (Highway B)

Problem: Determine legs of sight triangle.

Solution: From above table --- ISD_a = 50 m

ISD_b = 30 m

Note: This figure is not applicable for State highways.

INTERSECTION SIGHT DISTANCE
(No Traffic Control)

Figure 13.4A

Approach Grade (%)	Design Speed (km/h)									
	30	40	50	60	70	80	90	100	110	120
-6	1.1	1.1	1.1	1.1	1.1.	1.2	1.2	1.2	1.2	1.2
-5	1.0	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.2	1.2
-4	1.0	1.0	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
-3 to +3	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
+4	1.0	1.0	1.0	0.9	0.9	0.9	0.9	0.9	0.9	0.9
+5	1.0	1.0	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
+6	1.0	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9

Note: Based on ratio of stopping sight distance on specified approach grade to stopping sight distance on level terrain. The grade adjustment is based on the approach roadway grade only.

ADJUSTMENT FACTORS FOR APPROACH SIGHT DISTANCE BASED ON APPROACH GRADE

Figure 13.4B

13.4.2 Stop Controlled/Traffic-Signal Controlled

Where traffic on the minor road of an intersection is controlled by stop signs, the driver of the vehicle on the minor road must have sufficient sight distance for a safe departure from the stopped position assuming that the approaching vehicle comes into view as the stopped vehicle begins its departure.

The stopped-controlled criteria required will also apply to a signalized intersection. This is reasonable because of the increased driver work load at intersections and the potential conflicts involved when vehicles turn onto or cross the highway. These include:

1. violation of the signal,
2. right-turns-on-red,
3. signal malfunction, and/or
4. use of flashing yellow/red mode during part of the day.

If these criteria cannot be met, give consideration to prohibiting right-turn-on-red at the intersection or prohibiting the flashing mode. This determination will be based on field investigations and will be determined on a case-by-case basis.

13.4.2.1 Basic Criteria

The Department uses gap acceptance as the conceptual basis for its intersection sight distance (ISD) criteria at stop-controlled and traffic-signal controlled intersections. The intersection sight distance is obtained by providing clear sight triangles both to the right and left as shown in Figure 13.4C. The length of legs of these sight triangles are determined as follows:

1. Minor Road. The length of leg along the minor road is based on two parts. The first is the location of the driver's eye on the minor road. This is typically assumed to be 4.4 m from the edge of traveled way for the major road and in the center of the lane on the minor road; see Figure 13.4C. The second part is based on the distance to the center of the vehicle on the major road. For right-turning vehicles, this is assumed to be the center of the closest travel lane from the left. For left-turning vehicles, this is assumed to be the center of the closest travel lane for vehicles approaching from the right; see Figure 13.4C.

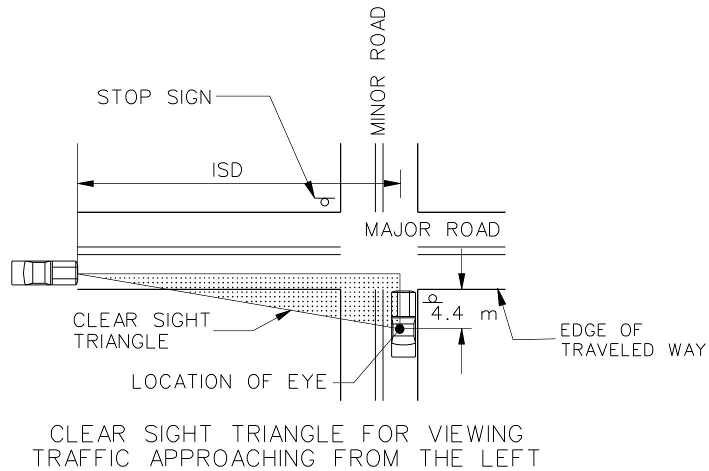
2. Major Road. The length of the sight triangle leg or ISD along the major road is determined using the following equation:

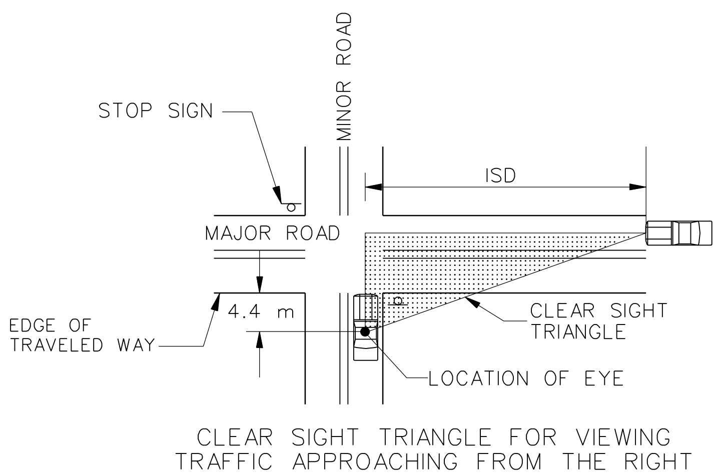
   $$ISD = 0.278\ V_{major}\ t_c \qquad \text{(Equation 13.4-1)}$$

   Where:

   ISD = length of sight triangle leg along major road (m)
   V_{major} = design speed of major road (km/h)
   t_c = critical gap for entering the major road (sec)

The critical gap time (t_c) varies according to the design vehicle, the grade on the minor road approach, the number of lanes on the major roadway, the type of operation and the intersection skew. Section 13.4.2.4 presents several examples on the application of ISD.





CLEAR SIGHT TRIANGLES (STOP-CONTROLLED) INTERSECTIONS

Figure 13.4C

Within this clear sight triangle, if practical, the objective is to remove, lower any object or trim lower branches that obstructs the driver's view. These objects may include buildings, parked or turning vehicles, trees, hedges, tall crops, unmowed grass, fences, retaining walls and the existing ground line. In addition, where an interchange ramp intersects the major road or crossroad near a bridge on a crest vertical curve, objects such as bridge parapets, piers, abutments or the crest vertical curve itself may restrict the clear sight triangle.

13.4.2.2 Vehicle Entering Major Roadway

To determine the intersection sight distance for vehicles turning left or right onto the major road, the designer should use Equation 13.4-1 and the critical gap times (t_c) presented in Figure 13.4D. Figure 13.4E, which solves Equation 13.4-1, provides the ISD values for all design vehicles on 2-lane, level facilities. The designer should also consider the following:

1. <u>Turn Maneuver</u>. There is only a minimal difference in the gap acceptance times between the left- and right-turning drivers. Therefore, only one critical gap time is provided.

2. <u>Multilane Facilities</u>. For multilane facilities, the gap acceptance times presented in Figure 13.4D should be adjusted to account for the additional distance required by the turning vehicle to cross the additional lanes or median. The following will apply:

    a. <u>Left-Turns</u>. For left turns onto multilane highways, add 0.5 seconds for passenger cars or 0.7 seconds for trucks for each additional lane, in excess of one, to be crossed by the turning vehicle. Assume that the left-turning driver will enter the left travel lane on the far side of the major road. For example, the gap acceptance time for a passenger car turning left onto an undivided six-lane facility would be 7.5 seconds plus 0.5 seconds for each of the two additional lanes needed to be crossed. The total gap time required is therefore 8.5 seconds.

    b. <u>Right Turns</u>. Because the turning vehicle is assumed to be turning into the nearest right through lane, no adjustments to the gap times are required.

3. Medians. For a multilane facility which does not have a median wide enough to store a stopped vehicle, divide the median width by 3.6 m to determine the corresponding number of lanes, and then use the criteria in Comment #2a above to determine the appropriate time factor.

Design Vehicle	Gap Acceptance Time (t_c) (sec)
Passenger Car	7.5
Single-Unit Truck	9.5
Tractor/Semitrailer	11.5

GAP ACCEPTANCE TIMES
(Right or Left Turn From Minor Road)

Figure 13.4D

Design Speed (V_{major}) (km/h)	ISD (m)		
	Passenger Cars	Single-Unit Trucks	Tractor/Semitrailers
30	65	80	95
40	85	105	130
50	105	130	160
60	125	160	190
70	145	185	225
80	170	210	255
90	190	240	290
100	210	265	320
110	230	290	350

Note: These ISD values assume a minor road approach grade ≤ +3%.

TWO-LANE INTERSECTION SIGHT DISTANCES
(Right or Left Turn from Minor Road)

Figure 13.4E

On multilane facilities <u>with</u> a median wide enough to store the stopped vehicle, the designer should evaluate the move in two steps; see Figure 13.4F:

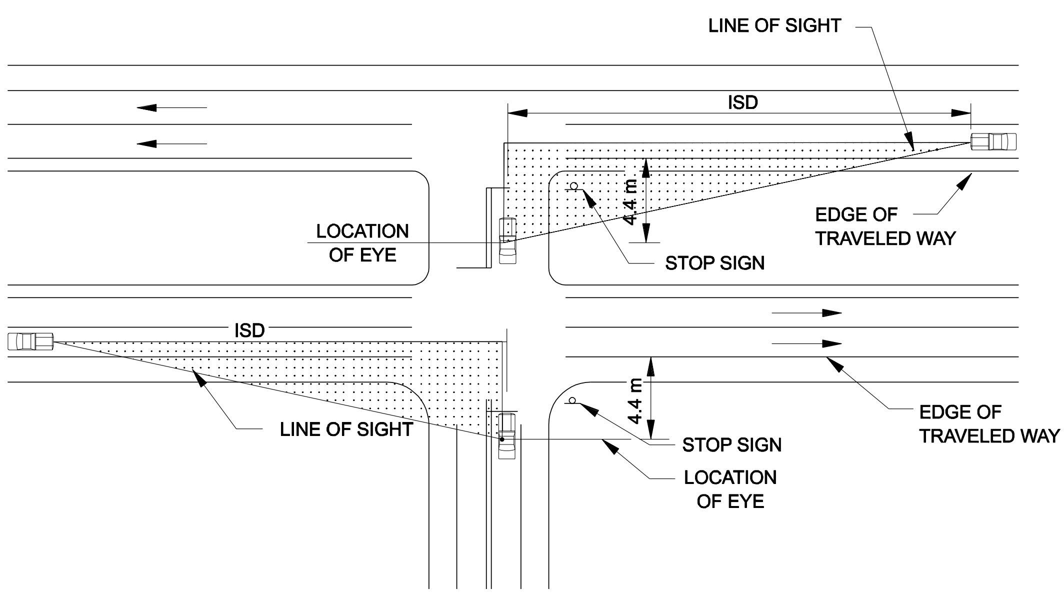
a. First, with the vehicle stopped on the minor road (the bottom portion in Figure 13.4F), use the gap acceptance times and distances for a vehicle turning right (Figures 13.4D and 13.4E) to determine the applicable ISD. Under some circumstances, it may be necessary to check the crossing maneuver to determine if it is the critical movement. Crossing criteria are discussed in Section 13.4.2.3.

b. Then, with the vehicle stopped in the median (top portion in Figure 13.4F), assume a two-lane roadway design and use the gap acceptance times and distances for vehicles turning left (Figures 13.4D and 13.4E) to determine the applicable ISD.

4. <u>Approach Grades</u>. If the approach grade on the minor road exceeds +3%, add the following times to the basic gap acceptance times in Figure 13.4D:

   a. <u>Left Turns</u>. Multiply the percent grade on the approach by 0.2 and add this to the base time gap.

   b. <u>Right Turns.</u> Multiply the percent grade on the approach by 0.1 and add this to the base time gap.



INTERSECTION SIGHT DISTANCE
(Divided Facilities)

Figure 13.4F

Use the adjusted t_c in Equation 13.4-1 to determine the applicable ISD. Do not apply the grade adjustment if the approach grade is negative.

5. Trucks. At some intersections (e.g., near truck stops, interchange ramps, grain elevators), the designer may want to use the truck as the design vehicle for determining the ISD. The gap acceptance times (t_c) for single-unit and tractor/ semitrailer trucks are provided in Figure 13.4D. ISD values for level, 2-lane roadways are presented in Figure 13.4E.

6. Height of Eye/Object. The height of eye for passenger cars is assumed to be 1070 mm above the surface of the minor road. The height of object (approaching vehicle on the major road) is also assumed to be 1070 mm. An object height of 1070 mm assumes that a sufficient portion of the oncoming vehicle must be visible to identify it as an object of concern by the minor road driver. If there is a sufficient number of trucks to warrant their consideration, assume an eye height of 2.4 m for a tractor/semitrailer and 1.8 m for single-unit trucks and buses. If a truck is the assumed entering vehicle, the object height will still be 1070 mm for the passenger car on the major road.

7. Skew. At skewed intersections where the intersection angle is less than 60°, adjustments may need to be made to account for the extra distance the vehicle needs to travel across opposing lanes. Using the procedures discussed in Comment #2 in Section 13.4.2.2 and/or Section 13.4.2.3, determine the appropriate ISD value based on this extra travel distance.

8. Examples. For examples on the application of ISD, see Section 13.4.2.4.

13.4.2.3 Straight Through Crossing Vehicle

In the majority of cases, the intersection sight distance for turning vehicles typically will provide adequate sight distance to allow a vehicle to cross the major road. However, in the following situations, the crossing sight distance may be the more critical movement:

1. where left and/or right turns are not permitted from a specific approach and the crossing maneuver is the only legal or expected movement (e.g., indirect left turns);

2. where the design vehicle must cross more than six travel lanes or, with medians, the equivalent distance; or

3. where a substantial volume of heavy vehicles cross the highway and there are steep grades on the minor road approach.

Use Equation 13.4-1 and the gap acceptance times (t_c) and the adjustment factors in Figure 13.4G to determine the ISD for crossing maneuvers. Where medians are present, include the median width in the overall length to determine the applicable gap time. Divide this width by 3.6 m to determine the corresponding number of lanes for the crossing maneuver.

Design Vehicle	Gap Acceptance Time (t_c) (sec)
Passenger Car	6.5
Single-Unit Truck	8.5
Tractor/Semitrailer	10.5

Adjustments:

1. *Multilane Highway. Where the design vehicle is crossing a major road with more than two lanes, add 0.5 seconds for passenger cars or 0.7 seconds for trucks for each additional lane in excess of two. See the discussion in Section 13.4.2.2 for additional guidance.*

2. Approach Grade. If the approach grade on the minor road exceeds +3%, multiply the percent grade of the minor road approach by 0.2 and add it to the base gap acceptance time.

GAP ACCEPTANCE TIMES
(Crossing Maneuvers)

Figure 13.4G

13.4.2.4 Examples of ISD Applications

The following three examples illustrate the application of the ISD criteria:

Example 13-1

Given: Minor road intersects a 4-lane highway with a TWLTL.
Minor road is stop controlled.
Design speed of the major highway is 80 km/h.
All travel lane widths are 3.6 m.
The TWLTL width is 4.2 m.
Trucks are not a concern.

Problem: Determine the intersection sight distance to the left and right from the minor road.

Solution: The following steps will apply:

1. For the vehicle turning right, the ISD to the left can be determined directly from Figure 13.4E. For the 80 km/h design speed, the ISD to the left is 170 m.

2. For the vehicle turning left, the ISD must reflect the additional time required to cross the additional lanes; see Comment #2 in Section 13.4.2.2. The following will apply:

   a. First, determine the extra width required by the one additional travel lane and the TWLTL and divide this number by 3.6 m:

   $$\frac{(3.6 + 4.2)}{3.6} = 2.2 \text{ lanes}$$

   b. Next, multiply the number of lanes by 0.5 seconds to determine the additional time required:

   (2.2 lanes)(0.5 sec/lane) = 1.1 seconds

   c. Add the additional time to the basic gap time of 7.5 seconds and insert this value into Equation 13.4-1:

   ISD = (0.278)(80)(7.5 + 1.1) = 191 m

   Provide an ISD of 190 m to the right for the left-turning vehicle.

3. Check the crossing vehicle, as discussed in Section 13.4.2.3. The following will apply:

a. First determine the extra width required by the two additional travel lanes and the TWLTL and divide this number by 3.6 m:

$$\frac{(3.6+3.6+4.2)}{3.6}=3.2 \text{ lanes}$$

b. Next, multiply the number of lanes by 0.5 seconds to determine the additional time required:

(3.2 lanes)(0.5 sec/lane) = 1.6 seconds

c. Add the additional time to the basic gap time of 6.5 seconds and insert this value into Equation 13.4-1:

ISD = (0.278)(80)(6.5 + 1.6) = 180 m

The 180 m for the crossing maneuver is less than the 190 m required for the left-turning vehicle and, therefore, is not the critical maneuver.

<u>Example 13-2</u>

Given: Minor road intersects a 4-lane divided highway.
Minor road is stop controlled.
Design speed of the major highway is 90 km/h.
All travel lane widths are 3.6 m.
The median width is 30.8 m.
Trucks are not a concern.

Problem: Determine the intersection sight distance to the left and right from the minor road.

Solution: The following steps apply:

1. For the vehicle turning right, the ISD to the left can be determined directly from Figure 13.4E. For the 90 km/h design speed, the ISD to the left is 190 m.

2. Determine if the crossing maneuver is critical; see Section 13.4.2.3. No adjustments are required to the base time of 6.5 seconds. Therefore, use Equation 13.4-1 directly:

ISD = (0.278)(90)(6.5) = 163 m

The crossing maneuver is less than the right-turning maneuver and, therefore, is not critical.

3. For the vehicle turning left, assume the passenger car is stopped in the median; see Figure 13.4F. The ISD to the right can be determined directly from Figure 13.4E. For the 90 km/h design speed, the ISD to the left is 190 m. The crossing maneuver will not be critical.

<u>Example 13-3</u>

Given: Minor road intersects a 2-lane highway.
Minor road is stop controlled.
Design speed of the major highway is 90 km/h.
All travel lane widths are 3.6 m.
The approach grade on the minor road is 4.5%.
Tractor/semitrailer trucks are a concern.

Problem: Determine the intersection sight distance to the left and right from the minor road.

Solution: The following steps will apply:

1. For the left-turning vehicle, the base gap acceptance time from Figure 13.4D is 11.5 seconds. Add the additional time due to the approach grade (0.2 seconds per percent grade) to the base gap time; see Comment #4 in Section 13.4.2.2:

   (0.2)(4.5) + 11.5 = 12.4 seconds

   Then, using Equation 13.4-1:

   S = (0.278)(90)(12.4) = 310 m

2. The ISD for the right-turning vehicle is determined similarly:

   (0.1)(4.5) + 11.5 = 12 seconds

   Then, using Equation 13.4-1:

   ISD = (0.278)(90)(12.0) = 300 m

3. The crossing maneuver will not be critical.

13.4.3 Yield Control

At intersections controlled by a yield sign, drivers on the minor road will typically:

1. slow down as they approach the major road, typically to 60 percent of the approach speed;
2. based on their view of the major road, make a stop/continue decision; and
3. either brake to a stop or continue their crossing or turning maneuver onto the major road.

Yield control criteria is based on a combination of the no control ISD discussed in Section 13.4.1 and the stop-controlled ISD as discussed in Section 13.4.2. To determine the applicable clear sight triangles of the approaches, the following will apply; see Figure 13.4H:

1. Crossing Maneuver. Use the following to determine the legs of the clear sight triangle; Illustration a in Figure 13.4H:

   a. Minor Road. The leg on the minor road approach can be determined directly from Figure 13.4I.

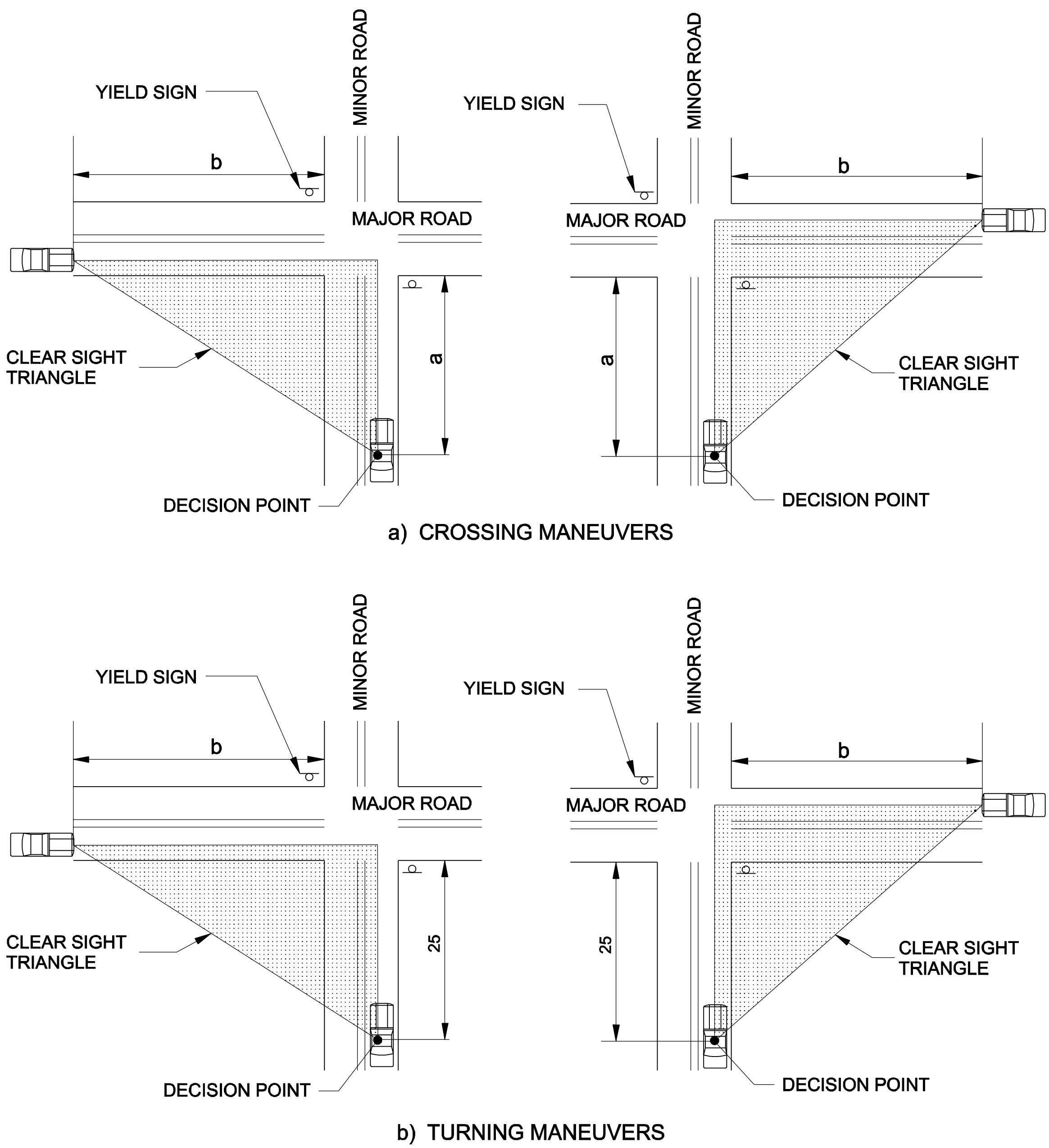
   b. Major Road. The leg on the major road is determined using the following equations and the times listed in Figure 13.4I:

$$t_c = t_a + \frac{w + L_a}{0.167(V_{minor})}$$

$$b = (0.278)(V_{major})(t_c)$$

Where:

b	=	length of leg of sight triangle along the major road (m)
t_c	=	travel time to reach and clear the major road in a crossing maneuver (sec)



INTERSECTION SIGHT DISTANCE APPLICATION
(Yield Control)

Figure 13.4H

Design Speed (km/h)	Approach Distance Along Minor Road[1] (a)(m)	Travel Time From Decision Point to Major Road (t_a)[1][2] (sec)
30	30	3.4
40	40	3.7
50	50	4.1
60	65	4.7
70	85	5.3
80	110	6.1
90	140	6.8
100	165	7.3
110	190	7.8

(1) For minor-road approach grades that exceed 3%, multiply by the appropriate adjustment factor from Figure 13.4B. Do not apply the adjustment factor to approaches with negative grades.

(2) Travel time applies to a vehicle that slows before crossing the intersection but does not stop.

ISD ASSUMPTIONS FOR YIELD CONTROLLED INTERSECTION
(Crossing Maneuver)

Figure 13.4I

t_a = travel time to reach the major road from the decision point for a vehicle that does not stop(sec) (use appropriate value for the minor-road design speed from Figure 13.4I, adjusted for approach grade, where appropriate)

w = width of intersection to be crossed (m)

L_a = length of design vehicle (m)

V_{minor} = design speed of minor road (km/h)

V_{major} = design speed of major road (km/h)

2. Turning Maneuvers. For the turning left or right vehicle, the approach legs are determined as follows; Illustration b in Figure 13.4H:

   a. Minor Road. The assumed turning speed from the minor road to the major road is 16 km/h. This corresponds to an approach distance of 25 m along the minor road leg.

   b. Major Road. To determine the legs along the major road, use the same procedures as discussed in Section 13.4.2.2 for the stop controlled intersection, Equation 13.4-1 and the critical gap times listed in Figure 13.4J. Because the critical gap times are longer than the stop-controlled gap times, it will be unnecessary to determine the sight distance criteria for the vehicle which stops at the yield sign.

Design Vehicle	Gap Acceptance Time (t_c)(sec)
Passenger Car	8.0
Single-Unit Truck	10.0
Tractor/Semitrailer	12.0

Adjustments:

If the approach grade on the minor road exceeds 3%, the following applies:

1. *For right turns, multiply the percent grade of the minor road approach by 0.1 and add it to the base gap acceptance time.*

2. *For left turns, multiply the percent grade of the minor road approach by 0.2 and add it to the base gap acceptance time.*

GAP ACCEPTANCE TIMES FOR YIELD CONTROL INTERSECTIONS
(Turning Maneuvers)

Figure 13.4J

13.4.4 All-Way Stop

At intersections with all-way stop control, provide sufficient sight distance so that the first stopped vehicle on each approach is visible to all other approaches. The ISD criteria for left- or right-turning vehicles as discussed in Section 13.4.2 are not applicable in this situation. Often, intersections are converted to all-way stop control to address limited sight distance at the intersection. Therefore, providing additional sight distance at the intersection is unnecessary.

13.4.5 Stopped Vehicle Turning Left

At all intersections, regardless of the type of traffic control, the designer should consider the sight distance needs for a stopped vehicle turning left from the major road. This is illustrated in Figure 13.4K. The driver must see straight ahead for a sufficient distance to turn left and clear the opposing travel lanes before an approaching vehicle reaches the intersection. In general, if the major highway has been designed to meet the stopping sight distance criteria, intersection sight distance only will be a concern where the major road is on a horizontal curve, where there is a median, or where there are opposing vehicles making left turns at an intersection.

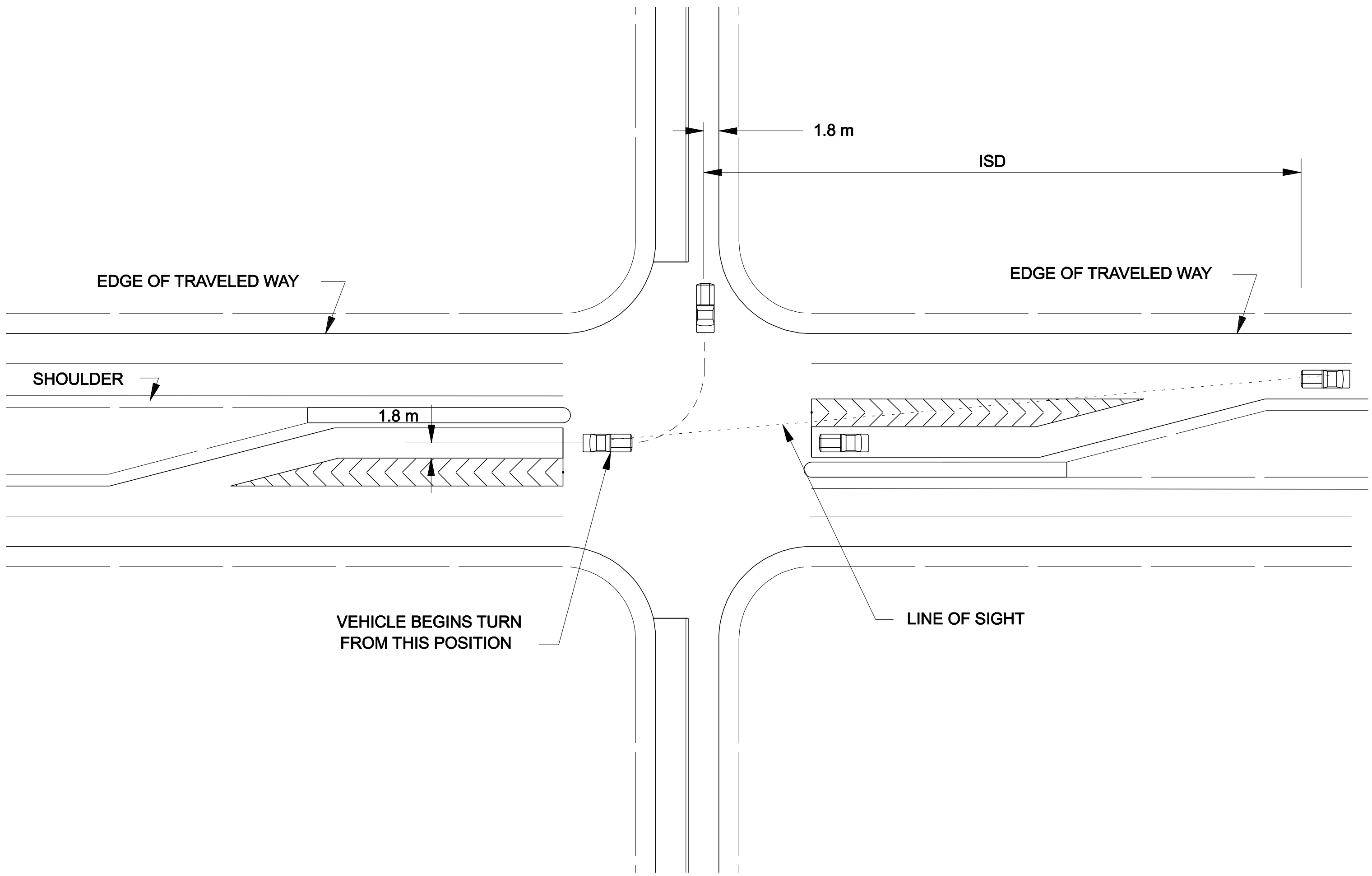
Use Equation 13.4-1 and the gap acceptance times (t_c) from Figure 13.4L to determine the applicable intersection sight distances for the left-turning vehicle. Where the crossing vehicle must cross more than one lane, add 0.5 seconds for passenger cars or 0.7 seconds for trucks for each additional lane in excess of one. Where medians are present, the designer will need to consider their effect in the same manner as discussed in Section 13.4.2.2. Figure 13.4M provides the ISD values for all design vehicles and two common left-turning situations.

13.4.6 Measures to Improve Intersection Sight Distance

The available ISD should be checked using the above noted parameters. If the ISD values from the above Sections are provided, no further investigation is needed. If the line of sight is restricted by either bridge railing, guardrail, other obstructions, or the horizontal and vertical alignment of the main road and the ISD value is not available, evaluate one or more of the following modifications, or a combination, to achieve the intersection sight distance:

1. remove the obstructions that are restricting the sight distance,
2. relocate the intersecting road farther from the end of the bridge,
3. widen the structure on the side where the railing is restricting the line of sight,
4. flare the approach guardrail,

5. revise the grades on the main road and/or the intersecting road,
6. close the intersecting road,
7. make the intersecting road one-way away from the main road, and/or
8. review other measures that may be practical at a particular location.



Notes:

1. See Figure 13.4M for ISD values.

2. See Section 13.4.5 for discussion and application.

INTERSECTION SIGHT DISTANCE FOR A STOPPED VEHICLE TURNING LEFT
(On Major Road)

Figure 13.4K

Design Vehicle	Gap Acceptance Time (t_c)(sec)
Passenger Car	5.5
Single-Unit Truck	6.5
Tractor/Semi-trailer	7.5

GAP ACCEPTANCE TIMES
(Left-Turning Vehicles from Major Road)

Figure 13.4L

Design Speed (Vmajor) (km/h)	ISD (m)					
	Passenger Cars		Single-Unit Trucks		Tractor/Semitrailers	
	Crossing 1 lane	Crossing 2 lanes	Crossing 1 lane	Crossing 2 lanes	Crossing 1 lane	Crossing 2 lanes
30	45	50	55	60	65	70
40	60	65	70	80	85	90
50	75	85	90	100	105	115
60	90	100	110	120	125	135
70	105	115	125	140	145	160
80	120	135	145	160	165	180
90	140	150	165	180	190	205
100	155	165	180	200	210	230
110	170	185	200	220	230	250

INTERSECTION SIGHT DISTANCES
(Left-Turning Vehicles from Major Road))

Figure 13.4M

13.5 INTERCHANGES

13.5.1 General

An interchange is a system of ramps in conjunction with one or more grade separations that provides for the movement of traffic between two or more roadways on different elevation levels. The operational efficiency, capacity, safety and cost of the highway facility are largely dependent upon its design. Chapter Twenty-nine of the *Traffic Engineering Manual* provides guidance in the design of interchanges including access guidelines, selection, operations, spacing, freeway/ramp terminals, ramps and ramp/crossroad terminals.

13.5.2 Responsibilities

The following units are responsible for the planning and design of an interchange:

1. Access Review. The Rail, Transit and Planning Division will identify potential sites for a new interchange. The Traffic Engineering Section will review the need for an interchange against the guidelines presented in Section 29.1.2. of the *Traffic Engineering Manual*.

2. Interchange Type Selection. Once it has been determined that an interchange is justified, the Traffic Engineering Section will determine the appropriate interchange type for the site.

3. Geometric Layout. The Geometrics Unit in the Traffic Engineering Section will be responsible for designing the interchange layout including the horizontal alignment, the preliminary profile grade line and ramp/crossroad intersection details.

4. Interchange Design. After coordinating with the Traffic Engineering Section, the Road Design Section will be responsible for determining the final vertical alignment, earthwork quantities, drainage design and contour grading plans. In addition, the Road Design Section will coordinate with the Traffic Engineering Section to determine the necessary access-control lines and right-of-way limits.

5. Detailed Sheets. The Road Design Section in coordination with the Geometrics Unit will be responsible for preparing the detailed sheets that will be included in the construction plans.

6. Consultant Projects. On consultant-designed interchange projects, the consultant will be responsible for the design of all elements including type selection, geometric layout, signing, electrical work, ramp/crossroad intersection details and detailed plan preparation. The Traffic Engineering Section will be responsible for reviewing these items.

13.6 APPROACHES

The designer is referred to the Department's *Approach Standards for Montana Highways* for the Department's criteria on approaches. This publication has been prepared by the Department's Traffic Engineering Section in conjunction with the Right-of-Way Bureau and the Maintenance Division.

These regulations are adopted and issued according to the authority granted to the Montana Transportation Commission and/or the Department of Transportation under current Montana Law. Unless otherwise provided or agreed to, they apply to all highways on the Federal-Aid System. The frequency, proper placement and construction of points of access to highways are critical to the safety and capacity of those highways. These regulations are intended to provide for reasonable and safe access to highways while preserving their safety and utility to the maximum extent practical. These regulations are not intended to alter or reduce existing or future access control or access limitations, nor are they intended to alter or supersede access which has been agreed to by appropriate written contract with the Department of Transportation.